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Scalability of Robotic Displays: Display Size Investigation

by Elizabeth S. Redden, Rodger A. Pettitt, Christian B. Carstens, and Linda R. Elliott

ARL-TR-4456 **May 2008**

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14. ABSTRACT

This study was an investigation of the effect of camera view display sizes on robotic tele-operation control performance in a realistic context. It took place at Fort Benning, Georgia, and used Soldiers from the Officer Candidate School. After training in the operation of the TALON[1] robot system, each Soldier completed exercises using four different display sizes that were chosen to match the size and resolution of displays that might be used by dismounted Soldiers for other purposes in the near future. The terrain, targets, and hazards were counterbalanced along with the display size to control for the effect of learning. Display size and usability for robotic driving were evaluated, based on objective performance data, data collector observations, and Soldier questionnaires.

[1]TALON is not an acronym.

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[1]DCS is not an acronym.

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1. Introduction

1.1 Statement of the Problem

Scalability has been given many different definitions, depending upon the background of the person defining it, the technology being considered, and the operational use of the technology. Typically, when interface designers talk about scalable interfaces they are referring to a design that ensures that development takes into account the requirement to change over time. This drives interfaces to be flexible and "future proof". Without this type of scalability, interface designs require a complete renovation when a small change is needed in the application. This is a broad definition of scalability and has application to robotic interfaces. For this experiment, we concentrated on a more narrow definition of scalability which is a component of the broader definition. We are concerned with the ability of interfaces to accommodate presentation on devices of different types and sizes as effectively as possible. Soldiers operate in a large range of environments, from the relatively stable and spacious environment of a tactical operations center (TOC) to the cramped and perpetual motion environment of a vehicle to the rugged and physically demanding environment of the dismounted Soldier. All these environments have an impact on the size and configuration of the robotic interface. It is easy to see that a dismounted Soldier cannot carry the relatively large controller that can be used in a TOC. This type of scalability of interfaces is very important because it ensures that training transfer is easy across environments and that interfaces can be tailored to the environment in which they are used.

Interface trends are moving away from "one size fits all" toward a scalable family of products with common architecture, but sizes depend on the role and mission. The key to ensuring that a system is scalable is to consider not only the range of devices that Soldiers will use but also their context of use. An example can be easily seen in e-mail access. Typically, individuals have used their desktop computers to access e-mail, but more frequently, they are now using personal digital assistants (PDAs) and cell phones to do the same job when they are outside their offices. One factor affecting scalability of displays to the environment is screen size. Designing for one "optimum" screen size may seem to be a good idea because it may seem that the presentation of the interface is being controlled. If a display is designed that only works on one "fixed" browser window size, it will not work well in the others. It might even be completely unusable if important features disappear off the edge of the screen.

Many current robots (i.e., the MATILDA[2], PackBot[3], and TALON[4]) provide a tele-operation interface that is large and heavy. A goal of Program Executive Office (PEO) Soldier Warrior is to

[2]Mesa Associates' Tactical Integrated Light-Force Deployment Assembly
[3]PackBot is a registered trademark of iRobot Corporation.
[4]TALON, which is a registered trademark of Foster-Miller, Inc., is not an acronym.

design and build an innovative universal robot controller that allows a dismounted Soldier to control and task various small robotic platforms without causing unnecessary additional weight and without bulky "add-ons" to the Infantry Soldier System. Since current robotic interfaces would add much weight to the dismounted Soldier, it is important to discover and document the range of interface sizes that can be used for robotic operations in different environments and to understand the trade-offs involved in tailoring the sizes to the environments in which they will be used.

The popularity of very large screen displays and small, portable, wearable computing devices is increasing. The motivation behind the development for many of the large screen displays is often to provide an immersive experience or a sense of presence for virtual reality and home theaters. There are several configurations for these displays (i.e., projection screen, liquid crystal display [LCD], plasma, etc.), and the prices for these systems are dropping. The use of large displays for robotic interfaces might allow a more immersive experience for the operator than is allowed by a smaller desktop size display (Tan, Gergle, Scupelli, & Pausch, 2003). Tan, Robertson, and Czerwinski (2001) found that the wide fields of view afforded by large displays also provided better cues to aid users in navigating virtual space. Although this avenue of investigation is an interesting one, the number of feasible display sizes (large and small) is too large to address in one experiment. This experiment focuses on the PEO Soldier goal of reducing the size of the interface for use by dismounted Soldiers in real-world environments and on the task of driving a well-marked course while situational awareness (SA) is maintained by the search for targets in the immediate area. In order to bound even the number of sizes of smaller displays, we focused on display sizes that are currently available (or will be available in the near future) to the dismounted Soldier. The thought here is that a Soldier might not have to carry a separate display for robotic control, but rather, s/he could control a robot using a display that s/he is already carrying. The four display sizes we investigated were the Force XXI Battle Command Brigade and Below (FBCB2) that is currently available in vehicles, the commander's digital assistant (CDA) that is being carried by lower echelon commanders, a PDA that is being considered for squad members by the Future Force Warrior (FFW) program, and a goggle-mounted display (GMD) that is being considered for squad leaders by the FFW program.

1.1.1 The FBCB2 Display

The FBCB2 forms the principal digital command and control (C2) system for the Army at brigade levels and below. It is a 7.3-pound, 2.36-inch by 13.1-inch by 9-inch high-resolution active matrix touch screen display (see figure 1). The screen is a super video graphics array 12.1 inches diagonal with 800x600-pixel resolution.

1.1.2 CDA Display

The CDA is an early "spiral-out" from Land Warrior that provides a tactical picture to company-level leaders and above. There is more than one model that uses the name CDA. The CDA, developed from Raytheon's air warrior digital kneeboard, measures approximately 7 by 10 by 2

inches and weighs 5.4 lb, including its battery. It has a 6.4-inch diagonal daylight readable 480x640 resolution color LCD with an integrated touch screen (see figure 2).

Figure 1. FBCB2 display.

Figure 2. CDA display.

1.1.3 PDAs

PDAs are potentially attractive interfaces for dismounted Soldiers because they are relatively inexpensive, lightweight, small, and extremely portable, and some feature touch-sensitive displays. Many standard PDA interfaces have been developed for a wide range of applications such as word processing, calendar management, calculators, educational tools, and mobile surveillance. The FFW digital assistants also display navigation and SA pictures and images received from team members. The Recon 400 X used by the FFW Soldiers during the Air Assault Expeditionary Force (AAEF) Spiral C had a display resolution of 240x320 pixels, a 3.5-inch diagonal display size, and weighed 17 ounces (see figure 3).

Figure 3. Vehicle target detection rates by distance, open field target detection, no smoke.

1.1.4 Head-Mounted Displays (HMDs) and GMDs

Small, wearable HMDS and GMDs are being developed that enable users to observe a high-resolution display without having to carry a bulky display or without restricting the user to small size and low resolution. These devices come in a variety of configurations (monocular, binocular, see-through, opaque, etc.). Some are mounted on straps worn around the head, some are mounted on helmets, and some are mounted on eyewear. The FFW program is investigating several of these displays for use by the squad and team leaders. Typically, these devices provide lightweight (~17 ounces) super-video graphics display, high resolution (800x600) pictures with a 1.425-inch diagonal picture. The device used in this study was a monocular GMD. Because this display was so close to the eye, its apparent size was like that of a 17-inch diagonal TV display (see figure 4).

Figure 4. GMD.

1.2 Objectives

The objective of this experiment was to determine what effect display size reduction has on the tele-operation (driving) of small robots and the operator's SA of the immediate vicinity of the robot.

2. Method

2.1 Participants

Thirty-two Soldiers from the Officer Candidate School (OCS), Fort Benning, Georgia, participated in the study. These Soldiers had experience as enlisted Soldiers and came from varied military occupational specialties (MOSs).

2.2 Instruments and Apparatus

2.2.1 TALON Robot

The TALON is a lightweight robot designed for missions ranging from reconnaissance to weapons delivery (see figure 5). Built with all-weather, day/night and amphibious capabilities, the TALON can operate during adverse conditions over almost any terrain. The suitcase-portable robot is controlled through a two-way radio frequency line from a portable operator control unit that provides continuous data and video feedback for precise vehicle positioning. It was developed for the Explosive Ordnance Disposal Technology Directorate of the U.S. Army's Armament Research, Development, and Engineering Center at Picatinny Arsenal, New Jersey, by the engineering and technology development firm of Foster-Miller. The TALON began being used in military operations in Bosnia in 2000, deployed to Afghanistan in early 2002, and has been in Iraq since the war started, assisting with improvised explosive device (IED) detection and removal.

Figure 5. TALON robot.

For this experiment, the TALON was equipped with a video camera that enabled the participants to maneuver the vehicle and assess enemy activity and IEDs along the road to the objective.

2.2.2 Robotic Vehicle Displays

Four different display sizes were used to conduct this experiment. The A, B, and C display configurations were presented on an iExplorer to control the number of variables present in the study. Both the iExplorer (see figure 6) and the GMD (see figure 7) were plugged into the existing TALON control system so that its radio could be used. However, the TALON control system joystick and display were not used.

Figure 6. The iExplorer display and TALON radio configuration.

Figure 7. The GMD and TALON radio configuration.

The four display configurations (sizes or types) were representative of displays that can be used in the field or that may soon be present. The display configurations used were

- Display A – A display based on the Stryker and Bradley FBCB2 display characteristics (a 10.4-inch diagonal screen with 800x600 pixels);
- Display B – A display based upon the CDA display characteristics (a 6.5-inch diagonal screen with 640x480 pixels);
- Display C – A display based upon the FFW PDA display characteristics (a 3.5-inch diagonal screen with 240x320 pixels); and
- Display D – A GMD display based on the FFW GMD display characteristics (a 1.425-inch diagonal screen with 800x600 pixels).

2.2.3 Robotic Driving Course

The robotic driving course consisted of an oval-shaped course with four different lanes. Each lane had three legs and a total length of approximately 300 meters (see figure 8). Leg A, the first leg of each lane (see figure 9), was marked with engineering tape and required the Soldier to drive as quickly as possible to the end of the leg. An obstacle placed on the path was situated at the end of the first leg. For Leg B, the operator was required to negotiate around the obstacle by

going off the path and then returning to the path by the shortest and easiest route (see figure 10). Mock-up enemy Soldiers, booby traps, IEDs, and mines (see figure 11) that could be clearly seen by the driving camera were placed along the rest of the lane (Leg C) between the obstacle and the objective (end of the course). The robotic operators tele-operated the TALON from inside a tent that was placed behind a berm that blocked the line of sight (LOS) between the operators and the course. The tent and its placement prevented the operator from tele-operating the vehicle by using LOS rather than the display. It also kept the operator and the equipment out of the elements.

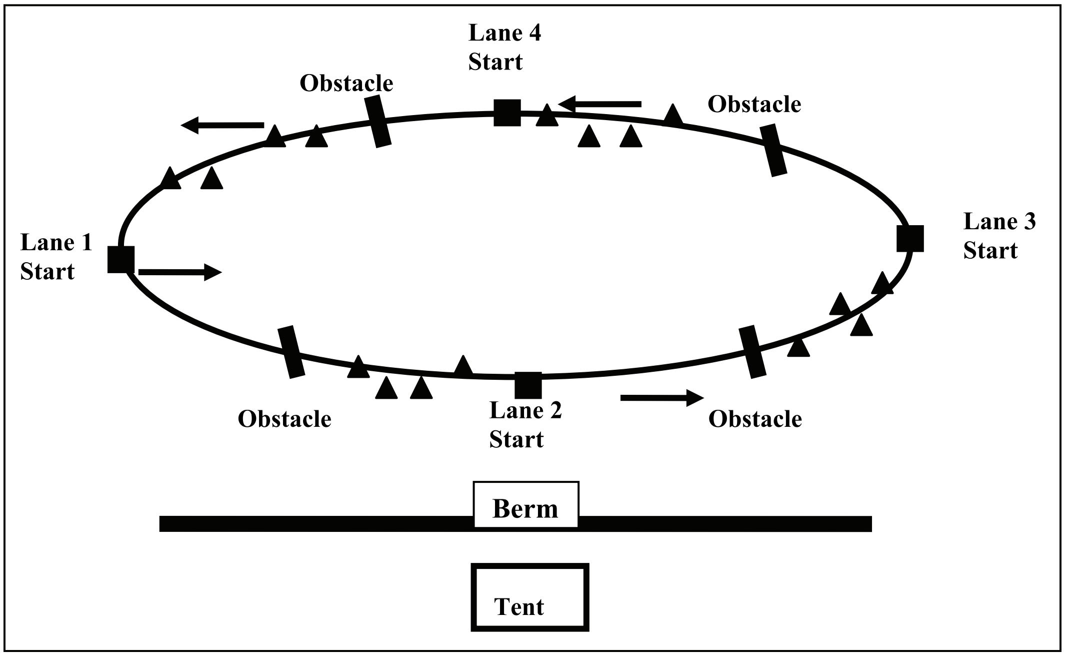

Figure 8. Robotic driving course.

Figure 9. Leg A, maneuver.

Figure 10. Leg B, obstacle avoidance.

Figure 11. Leg C, target detection and identification.

2.2.4 Questionnaires

Questionnaires elicited Soldiers' opinions about their performance and experiences with each of the display systems. The questionnaires asked the Soldiers to rate the devices on a 7-point Likert scale ranging from "extremely good/easy" to "extremely bad/difficult". Questionnaires were administered to each Soldier at the completion of the training course, at the end of each iteration with the displays, and at the end of the experiment.

2.2.5 National Aeronautics and Space Administration (NASA) Task Load Index (TLX)

The NASA TLX is a subjective workload assessment tool that allows subjective workload assessments on operator(s) working with various human-machine systems (Hart & Staveland, 1988). It uses a multi-dimensional rating procedure that derives an overall workload score based on a weighted average of ratings on six subscales. These subscales include mental demands, physical demands, temporal demands, own performance, effort, and frustration. It can be used to assess workload in various human-machine environments such as aircraft cockpits; command, control, and communication workstations; supervisory and process control environments; simulations; and laboratory tests.

2.3 Procedures

2.3.1 Training

The 32 experiment Soldiers reported in groups of four for one day each. Before the first training presentation, experiment Soldiers received a roster number, which was used to identify them throughout the evaluation. They were given an operations order that explained the robotic mission that they would undertake during the experiment. Driving requirements, obstacle negotiation requirements, and identification of threats were all explained and any questions the Soldiers had concerning the experiment were answered. Soldiers were then shown examples of the targets and the IEDs that they would be required to identify as they negotiated the robotic course. A representative from the Space and Naval Warfare Systems Command trained the Soldiers in the use of the TALON robot. Soldiers practiced tele-operating the robot on a training course that was similar to the actual course used during the experiment. This course required driving, obstacle negotiation, and identification of threats. Soldiers were trained with the actual TALON display rather than any of the experimental displays. Upon completion of the course, the Soldiers were given a questionnaire designed to assess their perception of the training adequacy. Questions about the amount of practice time given, the level of detail presented, and the adequacy of training aids were asked.

2.3.2 Demographics

Demographic data, as well as data concerning the Soldiers' Army and robotic experience, were documented for each Soldier.

2.3.3 Tele-operation Trials

Soldiers were assigned to displays and lanes according to the matrix presented in table 1. The matrix was constructed with the use of a 4x4 Greco-Williams square for treatment conditions, lanes, and preceding device (so that no device always followed another).

The Soldiers were required to tele-operate the robot within the course as quickly and efficiently as possible, negotiate around obstacles in the path, and detect and identify silhouette targets, IEDs, mines, and booby traps on the course. A data collector walked behind the TALON on each trial, documenting the following performance measures:

- Time to reach the end of each leg,
- The number of major times the driver went off course (*both wheels outside the marked course),*
- The number of minor times the driver went off course (*one wheel touched or went outside marked course)* on the first and third legs,
- The number of driving errors (*back-ups, turning in the wrong direction, etc*.) on each leg,
- The time to complete Leg A of the course,
- The time required to re-route around terrain obstacles (dynamic retasking) on Leg B,
- The number of enemy personnel detected and identified and the range of detection,
- The number of booby traps, IEDs, and mines detected and identified and the range of detection,
- The number of false threats found,
- The time to complete Leg C of the course, and
- The overall course completion time.

Table 1. Order of treatments and lanes.

Roster (Soldier)	Iteration							
	1		2		3		4	
	Display	Lane	Display	Lane	Display	Lane	Display	Lane
1, 9, 17, 25	A	1	D	4	B	2	C	3
2, 10, 18, 26	B	4	A	3	C	1	D	2
3, 11, 19, 27	C	2	B	1	D	3	A	4
4, 12, 20, 28	D	3	C	2	A	4	B	1
5, 13, 21, 29	C	4	B	3	D	1	A	2
6, 14, 22, 30	D	1	C	4	A	2	B	3
7, 15, 23, 31	A	3	D	2	B	4	C	1
8, 16, 24, 32	B	2	A	1	C	3	D	4

The Soldiers received the following written operations order:

Who: You are in 2nd Platoon, A company, 1st Battalion, 52nd Infantry Division

What: You are located in a forward operating base (FOB) that is located in a remote area near the capital of Iraq. Your perimeter must constantly be checked for IEDs and enemy personnel as your FOB has been targeted by anti-Iraqi forces (AIF). You have been tasked to reconnoiter the small trail around your perimeter to ensure that there are no IEDs, unauthorized militia, etc., and report any and all such activity. In an effort to avoid unmanned sensors in the area, there is a well-marked trail around the perimeter that unmanned ground vehicles (UGVs) can use, and movement outside this marked trail is not authorized. Concertina wire at different points around the perimeter must be avoided. The UGV route is

clearly marked up to the obstacle, and the marked lane continues on the other side of the obstacle. Obstacles can be traversed either to the left or right, depending on the obstacle; however, the route around the obstacle is not marked.

When: The time is the local time.

They were told to reconnoiter each leg of the route and to find as many of the targets as possible as quickly as possible. They were then instructed that they must be at the lane end point no later than 30 minutes after starting the course. They indicated each target to the data collector following the TALON who used a hand-held laser range finder to determine the detection distance and reported the distance to another data collector in the tent. Each target was labeled with a number. The trailing data collector radioed the target number that was found and the distance to the target to the recording data collector. He also radioed the number and type of driving errors, the number of times the Soldier went off course, the time for completion of each leg of the course, and the total course time.

The Soldiers tele-operated the robot using the four different display configurations (one on each of the four different course lanes). After each lane, the Soldier responded to questionnaire items concerning the display that was used and waited until the course was ready for the next iteration. At the end of the day, each Soldier completed a questionnaire concerning his or her overall assessment of each display configuration.

3. Results

3.1 Training

Soldiers rated the training course highly and stated that they had enough training time to feel confident that they could perform well on the course.

3.2 Demographics

The 32 OCS Soldiers who participated in this experiment averaged 8 years 3 months in the military. Twelve Soldiers had served in an infantry MOS. Seventeen of the Soldiers had been deployed in a combat area. Although only one had robotic experience, 27 Soldiers had driven a remote control car. The weights of the Soldiers ranged from the 40th percentile female to the 99th percentile male (130 to 260 pounds). Their heights ranged from the 5th percentile female to the 99th percentile male (60 to 80 inches). The average age of these Soldiers was 31 years. Eight Soldiers were left-eye dominant and seven wore prescription lenses. All but one Soldier had at least 20/20 corrected vision in one eye. The one exception had 20/25 vision in both eyes. See appendix A for detailed demographic information. Detailed results are presented in appendix A.

3.3 Tele-operation Trials

3.3.1 Course Completion Times

Mean times to complete each leg of the course and the entire course are shown in table 2. A series of repeated measures analyses of variances (ANOVAs), summarized in table 3, indicate that there was a significant difference among the display conditions for the time required to complete Leg B of the course. Figure 12 illustrates this finding. Follow-on pair-wise comparisons were conducted with the use of Holm's Sequential Bonferroni to control family-wise error rates. As shown in table 4, Leg B completion times were significantly longer (slower) with the D display than with the B and C displays.

Table 2. Time (min:sec) to complete course legs.

	Leg A		Leg B		Leg C		Total Course	
Display	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***
A	1:53	*0:32*	1:44	*1:14*	12:09	*4:21*	15:45	*4:44*
B	1:49	*0:37*	1:13	*0:36*	11:14	*3:10*	14:16	*3:40*
C	1:47	*0:34*	1:21	*0:38*	11:49	*3:40*	14:57	*3:54*
D	2:08	*0:51*	1:47	*0:52*	11:43	*3:56*	15:39	*4:26*

Table 3. Summary of ANOVAs, leg and course completion times.

Leg	F	df	p	η^2_p
A	1.97	3,93	0.123	0.060
B	4.49	3,93	0.005*	0.127
C	0.62	3,93	0.602	0.020
Total	1.55	3,93	0.207	0.48

* $p < .05$

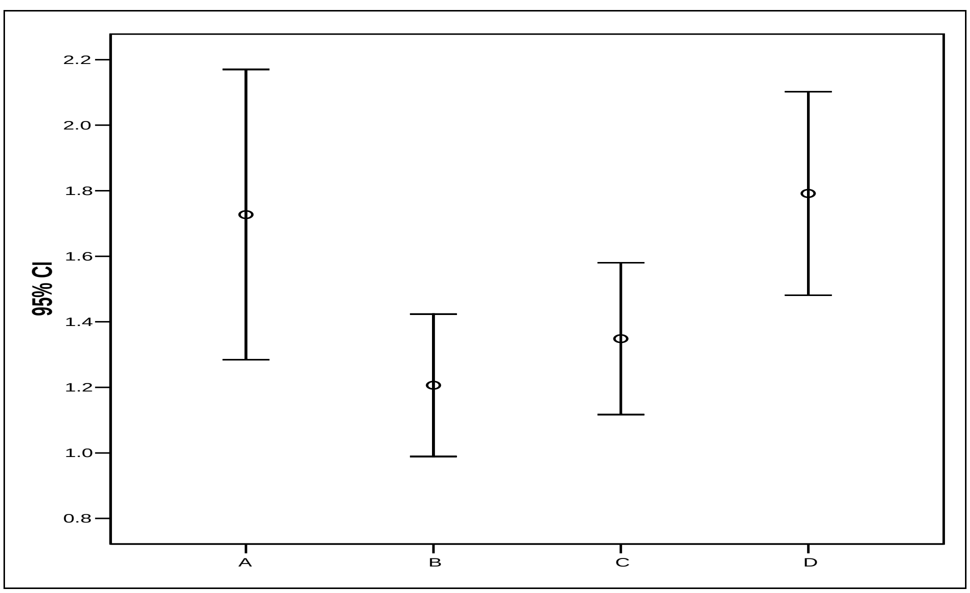

Figure 12. Mean times for each display on leg B (minutes).

Table 4. Follow-on pair-wise comparisons, leg B course completion times.

Display Pair	*t*	Df	obtained *p*	required *p*
A vs. B	2.16	31	0.039	0.0125
A vs. C	1.58	31	0.125	0.0167
A vs. D	-0.27	31	0.788	0.05
B vs. C	-1.34	31	0.189	0.025
B vs. D	-4.40	31	< .001*	0.0083
C vs. D	-3.48	31	.002*	0.01

* $p < .05$, *2 tailed*

3.3.2 Driving Errors

Table 5 shows the mean number of driving errors with each display size for the three legs. Repeated measures ANOVAs were conducted to test for differences among the means within each leg of the course. As shown in table 6, none of the ANOVAs yielded statistically significant results.

Table 5. Driving errors by leg.

	Leg A		Leg B		Leg C	
Display	Mean	*SD*	Mean	*SD*	Mean	*SD*
A	0.00	*0.00*	0.19	*0.54*	0.25	*0.72*
B	0.09	*0.30*	0.03	*0.18*	0.13	*0.71*
C	0.06	*0.35*	0.09	*0.30*	0.34	*1.21*
D	0.03	*0.18*	0.28	*0.68*	0.25	*0.80*

Table 6. Summary of ANOVAs, driving errors.

Leg	F	df	*p*	η^2_p
A	0.83	3,93	0.481	0.026
B	1.77	3,93	0.158	0.054
C	0.27	3,93	0.707	0.015

The mean numbers of major off-course events for each leg and each display condition are shown in table 7. A series of repeated measures ANOVAs, summarized in table 8, indicates that none of the differences among the means was statistically significant.

Table 7. Major off-course errors.

	Leg A		Leg B		Leg C	
Display	Mean	*SD*	Mean	*SD*	Mean	*SD*
A	0.09	*0.30*	0.38	*0.61*	0.03	*0.18*
B	0.09	*0.39*	0.25	*0.57*	0.06	*0.25*
C	0.03	*0.18*	0.19	*0.47*	0.03	*0.18*
D	0.16	*0.45*	0.22	*0.49*	0.09	*0.30*

Table 8. Summary of ANOVAs, major off-course errors.

Leg	F	df	*p*	η^2_p
A	0.69	3,93	0.561	0.022
B	0.87	3,93	0.460	0.270
C	0.57	3,93	0.635	0.018

Table 9 shows the average number of minor off-course errors on each leg of the course with each display. Repeated measures ANOVAs (table 10) indicate that none of the differences among the means was statistically significant.

Table 9. Minor off-course errors.

	Leg A		Leg B	
Display	Mean	*SD*	Mean	*SD*
A	0.16	*0.51*	0.91	*1.23*
B	0.25	*0.67*	0.81	*1.12*
C	0.19	*0.47*	1.59	*2.34*
D	0.38	*0.61*	1.16	*1.63*

Table 10. Summary of ANOVAs, minor off-course errors.

Leg	F	df	*p*	η^2_p
A	0.965	3,93	0.413	0.03
C	1.78	3,93	0.157	0.054

3.3.3 Target Detection and Identification

Table 11 shows the mean number of three-dimensional (3-D) silhouette targets detected and correctly identified for each display condition. Repeated measures ANOVAs (table 12) indicate that there were no significant differences among the means for target detection or identification.

Table 11. Mean 3-D silhouette targets detected and identified.

	Detect		Identify	
Display	Mean	*SD*	Mean	*SD*
A	8.41	*1.43*	8.16	*1.46*
B	8.72	*1.17*	8.38	*1.24*
C	8.69	*1.47*	8.44	*1.58*
D	8.28	*1.65*	7.94	*1.70*

Table 12. Summary of ANOVAs, 3-D silhouette targets.

Dependent variable	**F**	**df**	***p***	**η^2_p**
Target detection	0.86	3,93	0.463	0.027
Target identification	0.97	3,93	0.411	0.030

The mean number of IEDs detected and correctly identified is shown in table 13. The repeated measures ANOVAs summarized in table 14 indicate that there were no significant differences among the display conditions for target detection or identification.

Table 13. Mean IED targets detected and identified.

	Detect		**Identify**	
Display	**Mean**	***SD***	**Mean**	***SD***
A	4.66	*1.70*	4.09	*1.67*
B	5.03	*2.16*	4.38	*2.00*
C	5.31	*1.94*	4.81	*1.89*
D	4.41	*2.27*	3.91	*2.10*

Table 14. Summary of ANOVAs, IED targets.

Dependent variable	**F**	**df**	**p**	**η^2_p**
Target detection	2.20	3,93	0.093	0.066
Target identification	2.26	3,93	0.086	0.068

The mean ranges to detect targets within each display condition are shown in table 15. There were no significant differences among the displays for either type of target (table 16).

Table 15. Mean range (meters) to detect targets.

	3-D silhouettes		**IEDs**	
Display	**Mean**	**SD**	**Mean**	**SD**
A	9.49	2.88	2.55	1.13
B	10.25	3.58	2.86	1.45
C	9.16	2.75	2.67	1.22
D	9.07	3.20	2.65	1.52

Table 16. Summary of ANOVAs, target detection ranges.

Type of Target	**F**	**df**	***p***	**η^2_p**
3-D silhouettes	1.32	3,93	0.271	0.041
IEDs	0.49	3,93	0.688	0.016

Finally, the mean numbers of false target detections for each display condition are shown in table 17. A repeated measures ANOVA indicates no significant difference among the means: $F(3,93) = 0.69$, $p = .562$, $\eta^2_p = .033$.

Table 17. Mean number of false target detections.

Display	Mean	*SD*
A	0.31	*0.69*
B	0.47	*0.80*
C	0.28	*0.68*
D	0.44	*0.84*

3.3.4 Soldier Evaluation of Performance

Soldiers indicated that all display sizes were sufficient for driving and for providing adequate SA of the immediate surroundings for effective driving. Their mean subjective ratings for tele-operation tasks with the A, B, and C display sizes were very similar. Although many ratings of the D display size were also somewhat similar to the ratings for the other display sizes, D was rated the lowest for ease of performing every one of the tele-operation tasks. The tasks for which the D display size was most dissimilar from the other display sizes are shown in table 18.

Table 18. Mean subjective ratings for tasks with dissimilar ratings.

Task	Display A	Display B	Display C	Display D
Avoid obstacles	5.50	5.62	5.63	4.91
Localize the robotic vehicle within the environ-ment so that you can tell where the sides of the vehicle are located	5.41	5.31	5.66	4.94
See well enough to drive at slowest speeds	5.47	5.78	5.94	5.41
See well enough to drive at fastest speeds	4.28	4.63	4.88	3.94
Overall ability to perform driving tasks	5.03	5.31	5.63	4.69

Several problems were reported with tele-operating the robot, which had nothing to do with the displays. These included interference in the video transmission, screen black-outs, video lag, and freezing of the picture. Soldiers rated their ability to maintain SA as similar for each of the displays. There were several comments that SA was degraded because the camera on the robot had no view to the sides and rear and because there was no audio feed.

3.3.5 Soldier Evaluation of Individual System Characteristics

Table 19 displays the system characteristics whose mean subjective ratings were most dissimilar.

Table 19. Mean subjective ratings for system characteristics with dissimilar ratings.

System Characteristics	Display A	Display B	Display C	Display D
Comfort of viewing the display	4.81	5.12	4.91	4.00
Resolution (clarity)	3.47	4.25	4.75	3.88

The Soldiers rated the D display as the least comfortable to view. With the A, B, and C display sizes, the Soldiers moved their heads and changed their body positions to achieve the desired viewing distance. They indicated that the head positions did not detract from their comfort. However, the reasons they gave for rating the D display as less comfortable were primarily attributable to eye strain from viewing the display with only one eye. One Soldier also complained that he kept trying to turn his head to see farther to the left or right with device D, even though this

action had no effect on the area of camera regard. One Soldier commented that he had more difficulty finding targets with the largest display size (A) because he had to keep his eyes moving in order to scan the entire width of the display. Others complained that the largest display just had bigger, blockier pixels and appeared to have lower resolution than devices B and C. Several Soldiers stated that the smaller displays would definitely be advantageous for dismounted Soldiers.

3.3.6 Soldier Ratings of Physical Problems Experienced With the Display Sizes

Table 20 displays the number of Soldiers who experienced different types of physical problems when they wore each of the display sizes.

Table 20. Number of physical problems experience with each display size.

	Number of Responses			
Display	**A**	**B**	**C**	**D**
Eye strain	6	4	2	21
Tunnel vision	1	1	1	2
Headaches	0	0	0	1
Motion sickness	0	0	0	3
Nausea	0	0	0	1
Disorientation	1	1	0	4
Dizziness	0	0	0	1
Any other problems?	1	0	0	4
Total	**9**	**6**	**3**	**37**

Eye strain, motion sickness, headaches, and disorientation were reported by many more Soldiers with the GMD. In fact, 66% of the Soldiers reported eye strain from using the GMD. Many complained that they had to keep the other eye closed or cover it because the intensity of the disparate images coming into two different eyes was overwhelming. Detailed questionnaire results are shown in appendix A.

3.3.7 Soldier Subjective Workload

The analysis of the Soldiers' NASA TLX ratings for the effort required for operation of each display follows.

3.3.7.1 Analysis of Total Workload Scores

Table 21 provides the mean NASA TLX total workload scores for each display option, and table 22 shows the results of the follow-on comparisons. Differences among means were statistically significant (repeated measures general linear model [GLM]; $F_{3,93} = 9.494$; $p = 0.00$; $\eta^2 = 0.23$).

Table 21. Mean NASA TLX total workload scores by display option.

NASA TLX Total Workload	Mean	Std. Deviation	N
Display A	41.94	15.52	32
Display B	36.43	16.19	32
Display C	34.16	14.53	32
Display D	49.17	19.68	32

Table 22. Follow-on paired comparison analyses for mean NASA TLX total workload scores.

Paired Comparisons		t	N	p
Pair 1	A versus B	1.933	31	.062
Pair 2	B versus C	.884	31	.383
Pair 3	C versus D	-4.056	31	.000
Pair 4	A versus D	-2.254	31	.031
Pair 5	A versus C	2.529	31	.017
Pair 6	B versus D	-4.429	31	.000

3.3.7.2 Analysis of Mental Demand Scores

Table 23 provides the mean NASA TLX weighted scores for mental demand for each display option, and table 24 shows the results from the follow-on comparisons. Differences among means were statistically significant (repeated measures GLM; F 3,93 = 5.517; p = 0.02; η^2 = 0.15).

Table 23. Mean NASA TLX mental demand scores by display option.

NASA TLX Mental Demand	Mean	Std. Deviation	N
DISPLAY A	8.62	6.27	32
DISPLAY B	9.46	8.04	32
DISPLAY C	9.00	7.09	32
DISPLAY D	12.40	8.87	32

Table 24. Follow-on paired comparison analyses for mean NASA TLX weighted mental demand scores.

Paired Comparisons		t	N	p
Pair 1	A versus B	1.933	31	.062
Pair 2	A versus C	.884	31	.383
Pair 3	A versus D	-4.056	31	.000
Pair 4	B versus C	-2.254	31	.031
Pair 5	B versus D	2.529	31	.017
Pair 6	C versus D	-4.429	31	.000

3.3.7.3 Analysis of Physical Demand Scores

Table 25 provides the mean NASA TLX weighted scores for physical demand for each display option, and table 26 shows the results from the follow-on comparisons. Differences among means were statistically significant (repeated measures GLM; F 3,93 = 3.437; $p = 0.02$; $\eta^2 = 0.10$).

Table 25. Mean NASA TLX physical demand scores by display option.

NASA TLX Physical Demand	Mean	Std. Deviation	N
DISPLAY A	1.18	3.94	32
DISPLAY B	.56	1.39	32
DISPLAY C	.76	2.40	32
DISPLAY D	2.96	6.51	32

Table 26. Follow-on paired comparison analyses for mean NASA TLX weighted physical demand scores.

Paired Comparisons		t	N	p
Pair 1	A versus B	.870	31	.391
Pair 2	A versus C	1.395	31	.173
Pair 3	A versus D	-1.586	31	.123
Pair 4	B versus C	-.418	31	.679
Pair 5	B versus D	-2.384	31	.023
Pair 6	C versus D	-2.109	31	.043

3.3.7.4 Analysis of Temporal Demand Scores

Table 27 provides the mean NASA TLX weighted scores for temporal demand for each display option. Differences among means were not statistically significant (repeated measures GLM; F 3,93 = 1.222; $p = 0.30$; $\eta^2 = 0.04$).

Table 27. Mean NASA TLX temporal demand scores by display option.

NASA TLX Temporal Demand	Mean	Std. Deviation	N
DISPLAY A	5.8542	5.20266	32
DISPLAY B	5.2104	4.14990	32
DISPLAY C	6.0042	5.27774	32
DISPLAY D	4.4448	4.92785	32

3.3.7.5 Analysis of Performance Scores

Table 28 provides the mean NASA TLX weighted scores for self-assessment of performance for each display option. Differences among means were not statistically significant (repeated measures GLM; F 3,93 = 0.916; $p = 0.44$; $\eta^2 = 0.03$).

Table 28. Mean NASA TLX performance scores by display option.

NASA TLX Performance	Mean	Std. Deviation	N
DISPLAY A	9.65	6.89	32
DISPLAY B	8.35	6.61	32
DISPLAY C	7.75	5.80	32
DISPLAY D	8.26	6.21	32

3.3.7.6 Analysis of Effort Scores

Table 29 provides the mean NASA TLX weighted scores for effort for each display option, and table 30 shows the results from the follow-on comparisons. Differences among means were statistically significant (repeated measures GLM; $F\ 3,93 = 7.327$; $p = 0.00$; $\eta^2 = 0.19$).

Table 29. Mean NASA TLX effort scores by display option

NASA TLX Effort	Mean	Std. Deviation	N
DISPLAY A	7.63	5.75	32
DISPLAY B	6.93	4.62	32
DISPLAY C	6.71	5.64	32
DISPLAY D	10.90	7.35	32

Table 30. Follow-on paired comparison analyses for mean NASA TLX weighted effort scores.

Paired Comparisons		t	N	Sig. (2-tailed)
Pair 1	A versus B	.673	31	.506
Pair 2	A versus C	.864	31	.394
Pair 3	A versus D	-3.021	31	.005
Pair 4	B versus C	.258	31	.798
Pair 5	B versus D	-4.025	31	.000
Pair 6	C versus D	-3.957	31	.000

3.3.7.7 Analysis of Frustration Scores

Table 31 provides the mean NASA TLX weighted scores for frustration for each display option, and table 32 shows the results from the follow-on comparisons. Differences among means were statistically significant (repeated measures GLM; $F\ 3,93 = 6.007$; $p = 0.00$; $\eta^2 = 0.16$).

Table 31. Mean NASA TLX frustration scores by display option.

NASA TLX Frustration	Mean	Std. Deviation	N
DISPLAY A	8.98	9.23	32
DISPLAY B	5.89	7.14	32
DISPLAY C	3.92	5.11	32
DISPLAY D	10.21	9.58	32

Table 32. Follow-on paired comparison analyses for mean NASA TLX weighted frustration scores.

Paired Comparisons		t	N	Sig. (2-tailed)
Pair 1	A versus B	1.774	31	.086
Pair 2	A versus C	3.413	31	.002
Pair 3	A versus D	-.624	31	.537
Pair 4	B versus C	1.400	31	.171
Pair 5	B versus D	-2.911	31	.007
Pair 6	C versus D	-3.529	31	.001

3.3.8 Soldier Overall Preference

Soldiers were requested to rank order the displays in the order of their preference, with 1 being their favorite, 2 their second choice, etc. Table 33 displays the results from this ranking.

Table 33. Mean subjective rankings for display preferences.

MEAN			
A	B	C	D
2.66	1.93	2.23	3.21

Soldiers ranked the displays (table 33) in the same order that they rated the displays for overall ability to perform driving tasks (table 18). Once again, they demonstrated that they preferred the two smaller displays to the largest display and GMD. Figure 13 displays the number of times that each display size was chosen first, second, third, and fourth.

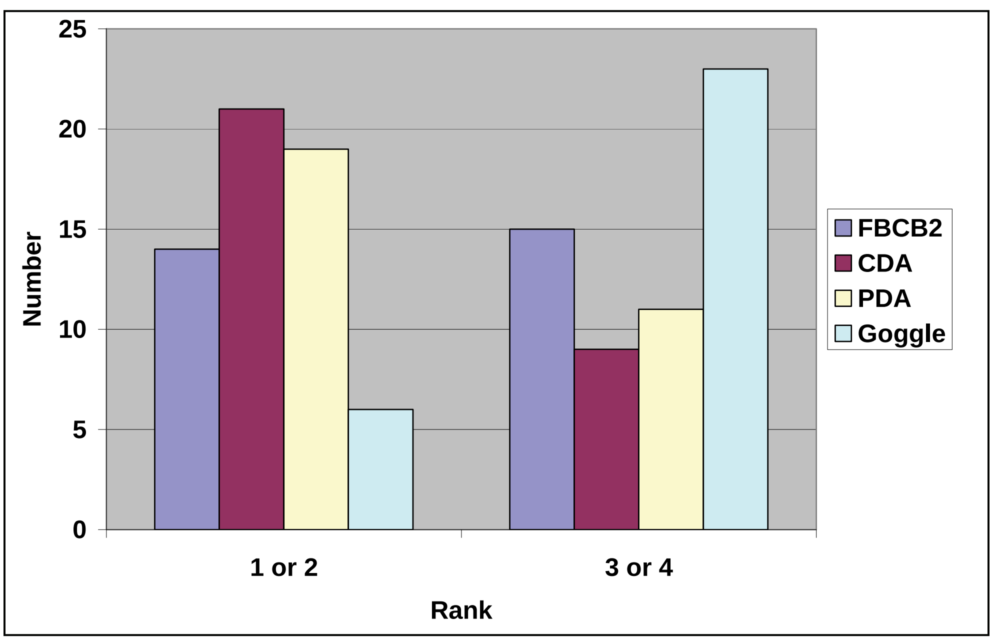

Figure 13. Number of times each display was chosen in the first two positions and the last two positions.

4. Discussion

It is important to consider the tasks that were examined during this field experiment when one is interpreting the results. The tele-operation task was confined to a marked course (Legs A and C) and to a very short off-road movement around an obstacle. The target detection task was limited to targets within the immediate vicinity of the robot. The "bottom-line" finding from this experiment is that Soldiers were able to perform the tele-operation and detection tasks required by this course with all four devices. All Soldiers completed the courses in similar amounts of time, with similar numbers of errors. Additional examination of the results, the literature, and the Soldier comments sheds further light on this finding.

Although the Soldiers performed *significantly* worse with device D (GMD) on only one measure (Leg B completion times), please note that there was a trend for worse performance with device D on every performance measure. Soldiers found it to cause significantly more work, effort, and frustration than Displays B and C and more mental demand than all three of the other displays. It was also the least preferred device and caused greatly increased physical problems. Soldiers complained of too much visual stimulation because of the strong visual images presented in each eye and binocular rivalry. Binocular rivalry is a term used when dissimilar images are presented to the two eyes, which causes an unstable state of alternating periods of monocular dominance. Overall dominance often appears as a fragmented mixture of the two eyes' views resulting in a dynamic, patchwork appearance (Lee & Blake, 1999; Mazumder, Drury, & Helander, 1997; Meenes, 1999). Most of the Soldiers closed their left eye or covered it with their hand in an attempt to reduce the problem.

On the positive side, the GMD (device D) used during this experiment was reported to be comfortable to wear (lightweight). Soldiers did express concern that the design did not let them wear their ballistic eye protection, but the manufacturer stated that there were plans to accommodate this problem. There were no reports of fogging (as is frequently the case with night vision goggles and some closed goggles such as the sun, wind, and dust goggles).

The smaller display sizes (devices B and C) did not appear to cause any problems for these Soldiers during the time periods when they used them. Most of the Soldiers positioned themselves closer to the smaller screens than they did to device A, which may have caused more accommodation and convergence of their eyes. Both accommodation and convergence have been cited as contributing to eye strain (Jaschinski-Kruza, 1988; Owens & Wolf-Kelly, 1987). However, the accommodative and convergent demand required when the smaller screen sizes were moved closer to the Soldiers' eyes to achieve better quality of inherent magnification did not appear to cause discomfort for the periods of time they used the displays. In fact, the Soldiers rated the comfort of viewing devices B and C higher than they did the comfort of viewing the larger display (device A) and the GMD (device D). This may have been because of their fairly young ages (most of the

Soldiers were under 30), or the viewing distance required by the smallest display size was not close enough to cause problems. This hypothesis is supported by a study of three viewing distances (24, 33, and 39 inches) in which Rempel, Willms, Anshel, Jaschinski, and Sheddy (2007) found that the near distance was associated with significantly less blurred vision, less eye irritation, fewer headaches, and improved convergence recovery than the middle and far distances.

The findings that Soldier performance with the smaller display sizes (devices B and C) was equal to performance with the larger display size (device A) are consistent with several other experiments that found no performance differences created by the effect of display size (Alexander, Wickens, & Hardy, 2005; Stelzer & Wickens, 2006; Stark, Comstock, Prinzel, Burdette, & Scerbo, 2001; Muthard & Wickens, 2004).

Although the Soldiers did not perform *significantly* worse with the largest display (device A) than they did with the smaller displays (devices B and C), there was a trend for worse performance with device A than with devices B and C and Soldiers rated it significantly more frustrating than Display C. Alexander, Wickens, and Hardy (2005) hypothesized that a smaller display could be of benefit to traffic surveillance by pilots, given that fewer eye movements would be required to scan the small display area as compared with a larger display area. One Soldier's theory for why he did not perform as well with Device A as he did with the smaller devices was consistent with this hypothesis. However, Martin-Emerson and Wickens (1997) found little added cost to increasingly longer eye movements. Another similar hypothesis is that the smaller screens present information within the subjects' macular vision, which is responsible for the clearest and most distinct vision and limit the need for the use of peripheral vision and the edges of the screen. Visual input to the macula occupies a substantial portion of the brain's visual capacity, and the smaller display sizes confine the information from the robotic scene to this area of highly concentrated cones. Further support for this hypothesis is provided by Parasuraman (1986) who reported an "edge effect" which he described as an observer's penchant to limit monitoring the edge of displays. Wickens, Muthard, Alexander, van Olffen, and Podczerwinski (2003) found that this edge effect resulted in peripheral changes being less likely to be detected and the possibility of additional effort and neck strain. The larger displays could thus hinder SA because a larger display area would fall into the peripheral vision of the operator. However, two experiments conducted by Muthard and Wickens (2004) to assess the impact of display size on flight control, air space surveillance, and goal-directed target search showed mixed support for these hypotheses. Pilots exhibited less flight path error with larger displays, and surveillance and search were unaffected by display size.

A factor that probably influenced the Soldiers' ratings of the largest display was the mismatch between the camera and the display resolutions, and this could have even had some effect on the objective results. They complained that the system did not have good resolution although it had the highest resolution of the devices used. The resolution of the 10.4-inch screen (Device A) was 800x600, but the source resolution of the camera was only 640x480. The match between the camera and display resolution with Device B could be the reason they rated the middle size screen as having the sharpest image. However, the camera used during this field experiment has

a resolution that is typical of cameras on small robots so the resulting mismatch could easily occur if larger displays with higher resolution are used.

As noted in the results section, several problems experienced during this field experiment were typical of robotic field operations and had nothing to do with display size. In field operations, operator performance is sometimes degraded because of problems with robotic systems. Carlson, Murphy, and Nelson (2004) reviewed data from 10 studies of 15 different UGVs and found that reliability of UGV performance in the field tends to be low (i.e., between 6 and 20 hours between failures). The common causes included limited wireless communication range and insufficient bandwidth for video-based feedback. These issues also often adversely impacted the human operator’s remote perception and ability to tele-operate. Two problems with connectivity and communication were especially prevalent. The first one was the frequent lag in video reception, which caused operators to have delayed responses. The other problem was similar. Several times, operators’ video pictures froze and the operators thought that the system was not responding. Thus, they continued to repeat the same command. In realty, the system was responding but the operator received no feedback, so the continued commands resulted in the operator driving the vehicle too far forward or backward.

Another problem that was noted during the experiment is glare. During this experiment, the Soldiers worked from a tent that helped reduce the problem with glare. However, dismounted Soldiers will not often have the luxury of working from a tent so that they are shaded from the sun, and glare is a definite problem that needs to be addressed.

5. Conclusions and Recommendations

Smaller devices can be used to display video that is sufficient for tele-operation and local surveillance with small, slow-speed robots. This makes more screen space available for other objects (if the total display size is larger than 3.5 inches) and enables the use of lower resolution cameras which would allow faster video processing since there are fewer pixels to be processed and less bandwidth is required if fewer pixels need to be transmitted. This finding does not address map display or touch screen operation and is limited to operators tele-operating robots while they are seated under a tent. Visual attendance should not be wider than the 5-degree macular vision (the actual width depends upon the viewing distance) in order to avoid visual scanning which can result in fatigue and missed data. Monocular helmet- or head-mounted displays should be carefully assessed to ensure that binocular rivalry and over-stimulation does not occur.

Other factors of scalability that should be addressed in subsequent experiments include

- the type of control device being used (i.e., mouse, touch screen, keyboard, etc.);
- structure or organization of the content of an interface (a desktop computer may use a presentation that is optimized when a high resolution monitor is used, while a user of a PDA might view the information in a text-only presentation);
- tactics, techniques, and procedures of dismounted robotic control, multimodal displays, and information requirements of users in different environments.

Further research on factors that may have an adverse impact on helmet- or goggle-mounted robotic displays needs to be performed if plans are made to use these displays for robotic tele-operation. Such factors include approaches to reduce interference between the scenes presented to two different eyes, potential problems with prolonged occlusion of one eye, the inability to use compensatory head movements to center the display on the visual field, and the effects of eye dominance on the use of monocular displays.

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Appendix A. Soldier Demographics

DEMOGRAPHICS
SAMPLE SIZE = 32

<u>**RANK**</u>	<u>**MOS/DUTY POSITION**</u>	<u>**AGE**</u>
E-4 – 1 E-6 – 7 E-5 – 14 E-7 – 8	Officer Candidate	31 years (mean)

1. How long have you served in the military? <u>8 years, 3 months</u> (mean)

2.a. Have you had an infantry-related job? <u>12</u> yes <u>20</u> no

b. If yes, how long? 5 years, 7 months (mean)

3.a. Have you been a fire team leader? <u>9</u> yes <u>23</u> no

b. If yes, how long? 1 year, 9 months (mean)

4.a. Have you been a squad leader? <u>12</u> yes <u>20</u> no

b. If yes, how long? 3 years, 8 months (mean)

5.a. Have you been deployed overseas? <u>22</u> yes <u>10</u> no

b. If yes, how long? 2 years, 2 months (mean)

6.a. Have you been deployed in a combat area? <u>17</u> yes <u>15</u> no

b. If yes, how long? 1 year (mean)

7. Corrected visual acuity: <u>27</u> 20/20 both eyes <u>1</u> 20/20 in one eye
<u>1</u> 20/20 and 20/40 <u>1</u> 20/25 and 20/25
<u>2</u> NR

8. Please list any visual problems you may have. None listed.

9. What is your height? <u>69</u> (inches) (range is 60-80)

10. What is your weight? <u>172</u> (pounds) (range is 130-260)

11. Which hand do you most often write? <u>28</u> right <u>3</u> left <u>1</u> NR

12. Which hand do you most often fire a weapon? <u>28</u> right <u>3</u> left <u>1</u> NR

13.a. Do you wear prescription lenses? _7_ yes _25_ no

b. If so, which? _3_ glasses _4_ contact lenses

14. Do you wear glasses or contacts while firing a weapon? _24_ yes _6_ no _2_ NR

15. Which is your dominant eye? _22_ right _8_ left _2_ NR

16. Have you every driven a robotic vehicle? _1_ yes _31_ no

EOD robots (1)

17. Have you ever driven a remote control car? _27_ yes _5_ no

18. Using the scale below, rate your level of experience with the following computer software and computer related activities:

1	2	3	4	5	6	7
No experience	Below average	Slightly below average	Average	Slightly above average	Above average	Expert

MEAN RESPONSE	
a. Microsoft Windows 98, 2000, XP, etc.	4.50
b. Computer based games	3.71
c. Army digital systems (e.g. FBCB2)	2.23
d. I would self rate my computer skills as:	4.47

19. Using the scale below, please rate the following Knowledge, Skills, and Abilities (KSA) related to infantry duties:

1	2	3	4	5	6	7
No experience	Below average	Slightly below average	Average	Slightly above average	Above average	Expert

MEAN RESPONSE	
a. Knowledge of tactics, techniques, and procedures (TTP).	4.00
b. Knowledge of map reading and orientation in field setting.	4.84
c. Knowledge of land navigation.	5.16
d. Knowledge of reconnaissance, surveillance, and target acquisition procedures.	3.34
e. Knowledge relating to communications equipment and communications procedures.	3.75
f. Communication skills (ability to use communications equipment & face-to-face communications to enhance mission accomplishment).	4.63

TRAINING
SAMPLE SIZE = 32

1. Using the scale below, please rate the training that you received in the following areas:

1	2	3	4	5	6	7
Extremely bad	Very bad	Bad	Neutral	Good	Very good	Extremely good

	MEAN
a. How to drive the robot	6.31
b. Time provided to practice driving the robot	6.06
c. How to complete Leg A (driving) of the course	6.50
d. How to complete Leg B (obstacle negotiation) of the course	6.31
e. How to complete Leg C (target detection and identification) of the course	6.41
f. Evaluation of the practice lane	6.16
g. How to identify different types of IEDs found on the course	6.19
h. How well do you expect to perform on the actual course	5.72
i. Overall evaluation of the training course	6.25

2. What were the easiest and hardest training tasks to learn?

Comments	No. of Responses
Easiest	
All.	2
Driving the Talon.	12
Controlling the robot.	2
Speed and direction.	1
Target/IED identification.	9
Understanding and negotiating the course.	2
Forward-rear mount.	1
Leg C.	1
Driving between the lanes.	2
Hardest	
Depth perception.	1
Getting accustomed to how the robot moves.	1
Maneuvering the robot effectively, and at a faster pace.	2
Driving the robot.	2
Negotiating obstacle at end of lane.	1
Staying in the lane.	1

Comments	No. of Responses
Turning sensitivity of robot.	1
Controlling the robot (joystick).	1
L-R sensitivity of joystick.	1
Adjusting to the use of one eye.	2
Target distribution on the monitor.	1
Identifying the objects on the screen.	1
Identifying smaller items.	1
Identifying some things because of shadows.	2
The sun made it hard to see and identify sometimes.	6
Overcoming negative visual limitations (seeing through the camera with sunny spots or not being able to look around without moving).	1
Target identification.	8
Leg A.	1
Viewing on the training screen.	1

3. What are your comments on the training course?

Excellent course.	4
Good, short course.	1
Good training.	4
Well organized.	2
Very professional.	1
Extremely beneficial to the execution of the actual course.	1
Easy and complete.	1
Easy to learn and use gear.	1
How useful these robots will be.	1
Passionate staff that is very excited.	1
Robot is easier to maneuver than I expected.	1
It is sufficient enough to get a feel for operating/negotiating the Talon along the course.	1
I have a fair amount of stick time (Iraq) on the Talon. It's good to see improvements being tested.	1
Because of the technical difficulties with the system (picture), I was unable to maximize its use on the lane.	1
I was very impressed with the way the robot handled. The camera and monitor combination were decent, but could definitely be improved.	
More training on identifying suspicious objects needed.	1
The obstacles weren't always easy to see or identify.	1
The screen gets a lot of distortion; flickers on rough spots on the track.	1
Could use more time get the look of the screen and the feel of the controls.	1
If camera was not as jumpy, would be helpful.	1

POST ITERATION
SAMPLE SIZE = 32

1. Using the scale below, please rate your ability to perform each of the following **navigation tasks** based on your experience with the display that you just used:

1	2	3	4	5	6	7
Extremely difficult	Very difficult	Difficult	Neutral	Easy	Very easy	Extremely easy

NAVIGATION TASKS	MEAN			
	A	B	C	D
a. Move in the correct direction	5.63	5.69	6.00	5.16
b. Avoid obstacles	5.50	5.62	5.63	4.91
c. Avoid pot holes	5.07	5.28	5.17	4.50
d. Assess down slopes for navigability	5.03	5.21	5.19	4.43
e. Assess side slopes for navigability	4.97	5.14	5.23	4.43
f. Identify any other terrain features that might have an adverse effect on the ability of the robot to maneuver through the terrain	5.06	5.03	5.35	4.48
g. Localize the robotic vehicle within the environment so that you can tell where the sides of the vehicle are located	5.41	5.31	5.66	4.94
h. Localize the robotic vehicle within the environment so that you can tell where the front of the vehicle is located	5.91	5.72	6.00	5.34
i. Localize the robotic vehicle within the environment so that you can tell where the back of the vehicle is located	4.65	4.58	4.84	4.29
j. Anticipate whether the ground clearance of the vehicle will allow negotiation of rugged terrain	4.75	4.68	4.87	4.22
k. Anticipate whether the turn radius of the vehicle will allow a turn	5.47	5.59	5.53	5.06
l. Identify whether you have navigated through this terrain in the past.	4.90	4.90	5.20	4.53
m. Identify if you are on the correct path	5.13	5.38	5.59	4.91
n. See far enough ahead to plan route in advance	5.16	5.25	5.38	4.81
o. See well enough to drive at slowest speeds	5.47	5.78	5.94	5.41
p. See well enough to drive at medium speeds	5.03	5.22	5.53	4.69
q. See well enough to drive at fastest speeds	4.28	4.63	4.88	3.94
r. Overall ability to perform driving tasks	5.03	5.31	5.63	4.69

Comments	No. of Responses
Display A	
Great size, view.	1
Overall driving ability was good.	1
Very easy to navigate.	2
Easy to navigate with big screen.	1
Steady picture throughout.	1
Speed and turn ability of the vehicle is fine.	1
Much easier to see all targets.	1
Robot was easy to move, but more difficult to turn and keep on track at the same time.	1
Navigation was off, but I feel that had a lot to do with the joystick being sensitive and not so much the robot.	1
For the most part, very fluid.	1
Video quality was poor throughout lane.	1
Resolution was very bad.	1
Reception was poor.	2
Camera distorting view.	1
Screen picture is distorted most of the time. Makes it difficult to identify targets and the correct path to travel.	3
Difficult to navigate over. Robot had to be moved manually.	2
When distorted, pixels were way too big.	1
Pixilation main issue on control screen which hampered my control. Had to stop several times to wait for a clearer screen.	1
Hard to judge right side due to camera placement.	1
A lot of technical interference.	1
Display B	
Clearest to this point.	3
Very easy to navigate.	3
Picture quality high except for a few spots.	1
Great picture when stationary, but deteriorates rapidly as you start to move.	1
Camera was at times a hindrance.	1
Joystick was overly sensitive, which made it hard to navigate.	1
Improve clarity of screen resolution.	1
Screen was blurred and distorted at times.	3
Lots of picture breakup throughout. I had limited visibility 30% of the route and complete blackout/whiteout 5% of the time.	1
PDA size was better.	1
Has to magnify the mega pixels too much.	1
The wind made reception very poor.	1
Bad reception to view camera feed from robot.	1
Display C	
Excellent view of area to navigate.	1

Comments	No. of Responses
Very easy to navigate even with smaller screen.	2
Worked well.	1
Performs well on smooth terrain with little to no vegetation.	1
By far best screen to complete tasks, but had to sit and pay close attention to screen due to size.	1
Smaller screen allows for more focus while navigating.	1
Navigation was more accurate the second time.	1
Picture clarity allowed user to see far enough to adjust for proper maneuver.	1
Way better than GMD, and no lag in video.	1
Other than flickering screen, I could see fairly well to navigate.	1
Reception was very bad at most times.	1
Poor visibility.	1
Poor picture quality.	1
Difficulties due to glare and broken feedback. Had to wait a few seconds for good feedback to return.	1
A little trouble seeing distance.	1
L to R axis did not respond well. The robot to controller log was bad at times and I frequently had to stop while attempting L to R movements. We even had to turn off the control consoled once to try to fix the issue.	1
Display D	
Excellent handling.	1
Easier than I thought it would be.	1
Control seems to be easier with this monitor.	1
The turning radius and full view picture is quite accurate.	2
Navigation is easy except during faded signals and screen saturation from direct sunlight.	1
Delay on the monitor.	1
Monitor inoperability (picture in/out).	1
Unable to identify lane, and had problems trying to ID and maintain situational awareness.	1
Very blurry picture with a lot of interference.	2
Picture was often broken up or distorted and pixilated, which caused driving to be more difficult.	
Very difficult to utilize compared to the screen views.	1
The eyes were fitted for a right-eye dominant wearer and I'm left-eye dominant, so the task was more difficult.	2
I had to stop the vehicle a lot in order to navigate.	1
Control of robot difficult due to grainy, pixilated view in glasses.	1
Often hard to see; pixels were not sharp.	2

Comments	**No. of Responses**
Not sure if it was lighting, but there were sections where the course was not visible.	1
It was hard to see in front, much less to the side.	1
Could not see distinctly to navigate well. Extremely frustrating.	1
Kept losing camera.	1
Static and sticking when bumpy.	1

2. Using the scale below, please rate your ability to ability to **maintain situation awareness around the vehicle** with the display that you just used:

1	2	3	4	5	6	7
Extremely difficult	Very difficult	Difficult	Neutral	Easy	Very easy	Extremely easy

SITUATION AWARENESS TASKS	**MEAN**			
	A	**B**	**C**	**D**
a. Locate mines	3.97	4.73	4.50	3.94
b. Locate IEDs	4.31	4.84	4.78	4.19
c. Locate booby traps	4.00	4.57	4.43	3.82
d. Locate enemy personnel targets	5.84	5.94	5.94	5.31
e. Overall situation awareness of the environment around the vehicle	4.75	5.16	5.28	4.66

Display A

Good platform; easier to estimate size and distance.	1
Could see better with this screen, but peripheral vision was limited so couldn't see until past the object.	1
With exception of resolution/contrast issues due to weak signal, overall situation awareness is mostly improved over all other screen sizes.	1
Most of the targets were easily identifiable. The personnel targets were the easiest; mines were the most difficult.	1
Better to ID smaller IEDs, than other instruments.	1
Very difficult to identify smaller objects.	1
Hard to determine IED vs. natural objects at times.	1
Display had a lot of interference.	1
Camera going in and out.	1
Screen picture is distorted which makes it difficult to distinguish a tree from a personal target. Pipe and pressure bombs are definitely impossible to identify on the given terrain.	1
Picture clarity affected situation awareness.	2

Comments	No. of Responses
If there was a way to minimize visual distortion, it would be very easy to locate targets.	1
Resolution should be improved.	1
Pixilation of camera view was severe.	1
The rougher the terrain, the more pixilation. Harder to see while moving at full speed.	1
Difficult to find engineer tape on the ground after negotiating obstacle.	1
Lost picture occasionally.	1
Display B	
Very easy to see enemy personnel and mines.	1
Picture allowed for situation awareness.	1
Pretty easy to differentiate size and natural vs. man-made.	1
Display not big enough at times.	1
I received a weak signal throughout the majority of the exercise resulting in poor image quality.	1
Resolution needs improving.	1
Had difficulty when screen was blurry.	1
Had to stop periodically to identify any potential targets.	1
Clarity.	1
When moving, image was choppy and would freeze.	2
Would be better if there was no screen breakup.	1
Camera made it very difficult to identify targets. A lot of fuzziness and camera going in and out.	1
Display C	
Easy to ID personnel targets.	1
Better video and little lag time.	1
Still very easy to locate IEDs and enemy personnel.	2
At times there was technical interference with the picture, but mostly you could see what was going on around you.	1
Identification depends mainly on clarity of visual pixilation.	1
Location was easy, but differentiating size can be tough.	1
Easier to use my peripheral vision than on the glasses.	1
If reception was better, it would be easier.	1
Picture quality and sunlight created many reflections, which were at times mistaken as IEDs.	1
Screen fade outs, and sun (direct light) made some areas of course difficult to gain situational awareness.	1
Only have view to front and no audio. This makes it difficult to have situational awareness.	1
Small screen made it tough at times.	1
Hard to ID IEDs because of scale.	1
It was very difficult to see at times because the camera was very scratchy.	1

Comments	**No. of Responses**
Display D	
Display is very good.	1
Observation to the front is ideal.	1
Takes time to become adjusted to picture with one eye. Puts strain on it and could become tiring after awhile.	4
Focus on the eyepiece was not 100%.	1
Observation from the sides is limited and there are no rear views available.	1
Faded signal screen saturations are major factors in situational awareness.	1
Often the screen was unclear, static or distorted so it made finding smaller objects unclear.	4
Targets appeared in the screen, but without prior knowledge of what they look like, it would be very difficult to ID them. It was not easy to ID something out of place in the lane because of the picture display.	1
Camera visibility made it difficult to identify targets at distance.	1
Very difficult to ID targets.	3
The only obvious targets were the personnel targets.	2
Difficult to determine size and differential between natural objects and IEDs.	1
A lot of interference with this route. I had to stop several times for the picture to clear up enough for me to continue.	2

3. During this trial, did you experience any of the following?

	Number of Responses			
	A	**B**	**C**	**D**
Eyestrain	6	4	2	21
Tunnel vision	1	1	1	2
Headaches	0	0	0	1
Motion sickness	0	0	0	3
Nausea	0	0	0	1
Disorientation	1	1	0	4
Dizziness	0	0	0	1
Any other problems?	1	0	0	4

Display A	
Size of screen was adequate.	1
Not as much static with this screen and closer to the ground so could see terrain better.	1
Choppy screen.	1

Comments	**No. of Responses**
Video in/out; required constant squinting.	1
Video quality poor; made task extremely difficult.	4
Hard to distinguish objects.	1
Feedback too broken to visualize.	1
Peripheral vision limited.	1
Disorientation due to static on screen.	1
Display B	
Good size screen.	1
Eyestrain when trying to identify targets at times.	1
Eyestrain caused by fuzzy screen.	1
Screen blurred and distorted at times.	1
Glare on the course and at the monitor in early morning.	1
Screen was jumpy; hard to focus.	1
Disorientation due to sun reflection.	1
Display C	
Size of picture was average.	1
PDA size of monitor works much better than the GMD system due to its size.	1
Targets are easier to identify without having to strain your eyes.	1
Eyestrain because camera fuzzy.	1
Eyestrain and tunnel vision due to screen size.	1
Could foresee headaches/migraines if watched through this screen a lot.	1
Display D	
Overall, good system.	1
Screen perhaps can be a little bigger.	2
Screen fuzzy at times.	1
Glasses strained my vision. Combination of bad screen and only one screen for one eye.	1
Only see directly in front.	1
I wasn't relaxed with my vision; was moving my head around.	1
Blocking out right side would help.	1
At times I had to close one eye in order to see.	2
Had to concentrate on keeping non-HUD eye closed and focus dominant eye on viewing at very close screen.	1
Eyestrain because of squinting.	2
Eyestrain due to trying to focus.	1
Right eye fatigue.	7
Had to close both eyes to get the best visual.	1
Would have been easier to use my left eye since I am left eye dominant.	2
I would develop a headache if used for extended period of time.	2

Comments	**No. of Responses**
Had no clue what I was looking at.	1
Disorientation after major video disruption.	1
Disorientation when spun around too quickly.	1
Visual distortion.	2
Nausea like I was driving.	1
Dizziness from no focus.	1
Motion sickness due to the rapid movement to focus in small monitor.	1

4. Using the scale below, please rate the following characteristics of the display that you just used:

1	2	3	4	5	6	7
Extremely bad	Very bad	Bad	Neutral	Good	Very good	Extremely good

DISPLAY CHARACTERISTICS	**MEAN**			
	A	**B**	**C**	**D**
a. Resolution (clarity)	3.47	4.25	4.75	3.88
b. Size of objects appearing in the display	5.19	5.22	4.81	4.63
c. Comfort of viewing the display	4.81	5.12	4.91	4.00
d. Contrast between objects	4.44	4.91	4.91	4.29
e. Display color	4.50	4.78	4.84	4.38
f. Display brightness	4.69	4.84	5.00	4.47
g. The effect of the size and shape of the display on mobility of the dismounted Soldier	4.81	4.94	5.09	4.97
h. Adequacy of a display of this size for tele-operating a robotic vehicle	5.31	5.16	4.97	4.69

5. Using the scale below, what is your **overall rating** of the display that you used this iteration?

1	2	3	4	5	6	7
Extremely bad	Very bad	Bad	Neutral	Good	Very good	Extremely good

MEAN			
A	**B**	**C**	**D**
4.75	5.06	4.96	4.40

Display A	
Good size display.	2
Easy to use.	2
No difficulty in positioning and operation.	1
Best view when identifying targets, IEDs.	1

Comments	**No. of Responses**
When screen was clear, this was the best screen to operate with.	1
Screen was good when signal was good.	2
I like the PDA view when driving, and the big screen when identifying targets.	1
Large objects can be easily seen.	1
Display size is adequate.	3
With improvements to the resolution, the display would be great.	1
This screen should be used for identifying objects close to the ground in plain view.	1
This size screen would be better suited for a vehicle. It may be too bulky for dismounted soldier.	1
Lots of interference, but otherwise great.	1
Get a better resolution camera with anti-shock and then it would be great.	1
Technical interference of display was only problem.	1
Video quality/clarity is poor; distorted.	8
Visual feedback was not as good as expected for the size of the display. Feedback too broken; had to stop many times during mission to relocate self and vehicle.	1
Lack of clarity made it very difficult to distinguish smaller objects.	1
Lack of contrast and almost eye blinding brightness at places didn't help.	1
Had difficulty identifying targets with the morning sun coming directly into the camera.	2
Pixels way too big.	1
Pixilation ruined the advantage of a larger screen. Fix this issue and the screen size.	2
There was less pixilation on the CDA size. I'd go with CDA only because of that reason.	1
Screen kept fading out.	2
Display B	
Best display to this point.	4
Display was very good.	2
Better clarity and contrast.	3
Good blend of size and mobility to display clarity.	1
Better driving view compared to the big screen.	1
Could navigate quickly and distinguish objects.	2
The display was small, but I could see objects of interest.	1
This size screen would be adequate given the resolution was better.	1
View was good, but when signal was weak, unable to ID or see smaller devices.	1

Comments	No. of Responses
If given the opportunity to periodically stop and let the picture focus, the system would be very effective.	1
Visual distortion while moving or standing was high.	2
Could see well when screen wasn't scrambling.	1
Screen breakup and light conditions make the robot much harder to operate.	1
Very blurry.	1
Camera pixels bad on rough terrain.	1
Resolution unclear at times, making it difficult to identify objects – even within 10 meters.	3
In bright sunlight, some objects are difficult to see.	1
Still too bright.	1
I prefer driving: PDA view.	1
I prefer location targets: big screen.	1
Wind really presented reception problems.	1
Would not recommend this display for the size of the robot. Too much interference which took time to correct.	1
Had the signal been strong throughout exercise, I believe I would have detected a substantial increase in man-made objects. On several targets, I could not get a good enough image to discern it from natural and man-made objects.	1
Display C	
This display was clearly the best of the four.	1
Best screen for clarity.	1
The displays were mainly good throughout test.	1
Easy to navigate course.	1
I would like to work with this system.	1
Overall, a good system.	2
Visibility and clarity were extremely good.	1
It was better driving the robot compared to the goggles. Anticipation on where I was going was a factor.	1
For the dismounted soldier, I feel this display is suitable and would provide ease of storing if needed.	1
When receiving correctly, looks very adequate to accomplish its mission.	1
Better than CDA, but not quite as good as the FBCB2.	1
Display, although small, could be used very easily.	1
Would serve well in theater with some enhancements.	1
Clarity was good, but I prefer the CDA just because it's bigger.	1
Clear, but the brightness was too high, which inhibited distant target viewing.	1
Sun glare made it difficult to see in certain directions.	1
Screen too small for me; wouldn't like to look at this long.	1

Comments	No. of Responses
Had to close in on display to achieve better recognition.	1
Display too small.	2
Miss some level of detail due to screen size.	2
Screen kept fading out.	1
Display changed colors frequently in brighter areas.	1
The reception was poor, so display was filled with static, and lines with discoloration. I needed to stop multiple times to allow the display to quit "freezing" before I could continue.	1
A lot of feedback from display made control difficult at times.	1
Signal strength needs improvement for remote use.	1
Need to enhance picture quality to make positive ID of IED and any other perceived threat.	1
There was a delay every now and then which would cause me to have to stop for a minute until the picture caught up.	2
There were lots of flashes and lines on the display which caused it to be difficult to see the terrain, objects, and lane.	1
Camera viewing was very difficult at times.	1
Display D	
Overall, good equipment.	1
I was really impressed with the clarity of the picture and precision of the turning radius.	1
Focus seemed clearer.	1
The size and fit would be ideal for a dismounted soldier.	1
Adapted to size quickly.	1
Would be perfect for small, light units if picture was clearer.	1
Although awkward getting used to a HUD, it provided a better than the PDA size viewer.	1
Display was very clear while the robot was still, but broken up during movement.	1
If the eyepiece (left/right eye dominant) and the distortion was corrected, this would be a great piece of equipment.	2
Needs great improvement.	1
Least favorite of all.	1
Better definition, but still way too bright with not enough contrast between objects.	1
Could be interesting to try under different light. There were times when the picture was great and other times when it was poor.	1
A little weird using only one eye, but otherwise the resolution and color were good.	1
If there could be a way to see the display with the right eye while "blocking out" the left eye, it would allow me to concentrate a lot more on the tasks at hand.	1

Comments	**No. of Responses**
Tried to drive with both eyes, but it was easier to close my left eye. I was trying to put myself in a real situation that I have to be aware of my surroundings also while my other eye is concentrating on the display.	1
This display method is extremely uncomfortable to use as it puts strain on both eyes. It was extremely difficult to see and monitor the movements of the robot because of poor picture quality and resolution.	1
Uncomfortable due to using one eye.	2
Eye fatigue occurred quickly during exercise.	1
Display sight picture was at times glaring, making it difficult to see the path of the objects.	1
The size of the display was not the major issue; the pixilation and poor clarity were.	1
Everything listed in "display characteristics" (i.e., picture, brightness, color and objects) needs to improve to make this system a more effective war fighting tool.	1
Signal strength and direct sun saturation are the biggest impediments.	1
Eyepiece lacks clarity.	2
Too much delay in video.	1
This was the most difficult viewing thus far.	1
Not soldier friendly.	1
Unable to visualize or figure out where or what I was doing; frustrating!	1

END OF EXPERIMENT
SAMPLE SIZE = 32

1. Please rank order the displays in the order of your preference – with 1 being your favorite, 2 your second choice, etc.

MEAN			
A	**B**	**C**	**D**
2.66	1.93	2.23	3.21

<u>**Comments**</u>	<u>**No. of Responses**</u>
<u>**Display A**</u>	
Biggest and clearest.	2
Easiest to pick out objects on.	1
Best contrast in order to ID potential IEDs.	1
Size makes it rank well with me.	3
Good tool.	1
Easiest.	3
Enjoyed larger screen, but pixilation and clarity are an issue.	1
Display needs to be improved.	1
Largest display was not at clear.	4
Big enough for target ID, but when reception was bad, the big pixels distorted the picture.	1
Broken up and distorted.	4
Resolution is bad.	1
Couldn't keep picture.	1
<u>**Display B**</u>	
Ranking totally based on maneuverability and ability to locate IEDs, etc. I would rather have the best equipment than the equipment that is the lightest.	1
Easy to use.	2
Great compromise between size and clarity.	3
Good size.	4
Large enough to be comfortable and portable.	2
Very clear.	6
OK; some static.	1
Too big for combat soldier.	1
Too large to carry.	1
Not very good.	1
Bad resolution for its size.	1

Comments	No. of Responses
Display C	
Good clarity.	7
Good because resolution was optimal relative to the size of the display.	1
Good for soldier mobility.	1
Best mix of size and clarity.	1
Easier to drive/navigate.	2
Easy to use.	3
No problem with the camera.	1
Good size; easy to carry.	1
Size is best for dismounted troops.	1
Most adequate size relative to maneuverability.	1
Tougher than the others.	1
Had better graphics.	1
Liked the portability. It is small enough and can be easily put in a ruck or attached. Weighs less and the screen size is optimal for a good view to ID threat.	2
Had to get real close to screen, so it wasn't so clear.	1
Too small.	3
Last resort. Straining eyes an issue.	1
Display D	
Size is best for dismounted troops.	1
I like the size.	2
Good for functionality.	1
Ability to localize objects in the ground.	1
The most convenient item.	1
Had the most clarity.	1
Good idea, but needs some black backdrop/shade to be effective.	1
The clearest, but had to hold goggles close to face in order to use well.	1
I felt good with this display because it forced me to pay more attention because I only had the use of one eye and I thought the technical side was the best.	1
Good except for the ability to use only one eye.	2
Could be very good if clarity was increased.	1
Made my eyes tired when keeping one eye closed for extended period of time.	5
Using one eye gave me a headache.	1
The eyes cause me to be slightly motion sick.	1
I had to close one eye the entire time because I am left-eye dominant.	1
While still clear for the most part, it was somewhat distracting as I found myself moving my head in a futile attempt to increase the view.	1

Comments	No. of Responses
Uncomfortable.	3
Picture was way too small.	2
Focus was not good.	1
Harder to use.	2
Required too much effort to see.	2
Hard to see through.	1
The resolution (pixeling) was not the same across the board.	1
Most ineffective due to constraints of vision.	1

2. Do you have any suggestions for ways to increase the effectiveness of the displays?

The displays need to be clearer; less distortion.	6
Use the most effective display that produces maximum results and is comfortable to the user.	1
Improve resolution.	3
Reduce the fading out of display.	1
Work on pixilation.	2
More pixels on some of the larger displays. The feed from the camera gets distorted quite easily with movement.	1
Possible use the HUD with both eyes.	1
Increase the quality of viewing picture. Soldier would benefit from clear picture, especially concerning IED detection.	1
Improve overall view (color, contrast, brightness, etc.).	2
Adjust the brightness so that clarity can be maintained in bright or darker conditions.	1
Enhance the contrast by lowering the brightness. The glare sometimes diminished contrast to the point that you couldn't see the object until it was right there.	1
Match the view screen to the dominant eye.	1
Use the new LCD or plasma tech with system to enhance its display.	1
Better optics and increase video transfer data rate.	1
If the camera could move from side to side while the robot is stopped to check on items visualized.	1
Cameras to monitor displays can be better.	1
Better visual image from the camera.	1
The ability to move the camera while leaving the robot on its current heading.	1
Put some sort of sun visor on the camera. Sun made it difficult to see.	1
Keep the weight low and compact.	1
Add a manual zoom adjustment.	1

Comments	**No. of Responses**
The wind affected the display on several iterations.	2
Shaking of display over bumps.	1
Improve signal strength to improve remote operations.	2
Better signal quality.	2
I prefer the FBCB2 size, but the mega pixels seemed stretched and more grainy.	1
Better antennas for better reception.	1
The transmission and reception quality needs to be better for this system to be combat effective.	1
Difficult to differentiate between shadows from the trees and IEDs.	1

3. Do you have any suggestions on ways to improve the driving training course?

No, the course was helpful.	6
Good training.	3
White engineer tape is perfect but not all in the course.	1
Use a different color engineer tape to highlight the course. Neon colors work best.	1
Have more than one practice session.	1
Should be trying this in an urban area and roads. Our soldiers are not operating in the woods for the most part in Iraq and Afghanistan.	1
Integrate more urban obstacles, i.e., small buildings, cars, etc. to better simulate the environment soldiers will encounter in Iraq or Afghanistan.	1
Give trainees a course where they can see their robot reacting to their joystick movements.	1
Course was set up well with different kinds of terrain. Maybe a little more sloping terrain.	3
Incorporate small ditch or trench.	1
Display needs to be improved.	1
Go from smooth surface with gentle corners to off-roading with hills and complex corners.	1
Point out what each item is on the screen as they are seen.	1
More turns and targets.	1
Take sun into effect when picking route.	1
Left/right sensibility a little fast.	1
Have a smaller hand device.	1
Improve the image that is transmitted to image screen to have less distortions.	1

4. Do you have any suggestions on ways to improve the driving lanes that you negotiated?

Comments	**No. of Responses**
No, good.	4
Lanes were well planned.	1
It's a good thing we had a trial first before we went to the lanes.	1
Make the courses a little more difficult.	1
Electronic interference was the only bad aspect of it.	1
Incorporate urban terrain, night time with night vision and desert-like conditions.	2
Try to use training aides more realistic to theater (artillery shells or mortars, etc.).	1
Include slide slopes, potholes, muddy terrain, and water holes along the course.	1
Have buildings and curbs.	2
More hills. These are harder to navigate and might show other flaws.	4
More turns.	1
Add some length to the course; more targets.	1
Don't stop when robot goes outside of lane. Give leeway to user to find way back.	1
Take sun into effect as well.	1

5. Using the scale below, please rate the importance of the following information that is needed for tele-operating a robot.

1	2	3	4	5	6	7
Extremely Unimportant	Very Unimportant	Unimportant	Neutral	Important	Very Important	Extremely Important

	MEAN
a. Heading information	5.16
b. Relative distance to obstacles	5.47
c. Depth of pot holes	4.81
d. Information on navigability of down slopes (tilt meter)	4.94
e. Information on navigability of side slopes (tilt meter)	5.03
f. Identification of any other terrain features that might have an adverse effect on the ability of the robot to maneuver through the terrain	5.41
g. Ability to determine where the sides of the vehicle are located. (sides are in the camera field of view or are marked on the screen)	5.31

(cont)

	MEAN
h. Ability to determine where front of the vehicle is located	5.69
i. Ability to determine where back of the vehicle is located	4.84
j. Information concerning whether the ground clearance of the vehicle will allow negotiation of rugged terrain	5.12
k. Indication of the turn radius of the vehicle	5.16
l. Information on the terrain closer than 6 inches in front of the vehicle	4.94
m. Information on the terrain 5 to 15 feet in front of vehicle	5.66
n. Information on the terrain greater than 15 feet in front of vehicle	5.22
o. Information on current speed of the vehicle (speedometer)	4.34
p. Information on vehicle revolutions per minute	3.66
q. Information on the way the vehicle motor sounds	4.06
r. Information on other noises present in the vehicle's environment	5.03
s. Information concerning the color of objects in the environment (color vs. black and white camera)	6.16
t. Information concerning objects on the side of the vehicle (side facing cameras)	5.31
u. Information concerning objects behind the vehicle (back facing camera)	5.28
v. Information concerning the condition of the vehicle tires/tracks.	4.44
w. Information concerning the temperature of vehicle	4.22
x. Feedback on the ruggedness of terrain.	4.81
y. Information concerning any delay between the time the operator sends a vehicle command and the time that the vehicle responds (i.e., how long after a stop command is sent before the vehicle actually stops)	5.66
z. Feedback concerning whether or not the vehicle correctly received a command	5.72
aa. Battery status	6.19
bb. Fuel status	6.19
cc. Vehicle temperature	4.97
dd. Other information requirement (if any)	5.80

6. What are your comments on information needed for tele-operating a vehicle?

Robots surpassed my expectations.	1
Great experience. Happy I could contribute my input.	1
Good system.	1

Comments	**No. of Responses**
Picture was clear.	1
Too heavy (transport big/small).	1
Hard to maneuver the robots due to the feedback in the screens being so choppy and distorted.	1
Improve picture and ID capability.	1
Better optics and training.	1
At least one camera with telescoping potential.	1
Signal strength is the biggest contributor to overall ability to discern objects in viewer. Needs a very good camera and a very strong/consistent signal.	1
If camera had swivel capability to see on each side of the vehicle.	1
Thermal will help ID people and running vehicles.	1
Maybe an instrument panel/gauge cluster or display on monitor of above items.	1
When going uphill, it is more difficult to see close to the front of the vehicle.	1
It could be better if there was control on speed on the robot.	1
It could be better if there was a separate control on the camera and robot (i.e., zoom in/out, left/right/forward/rear, etc.)	1

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